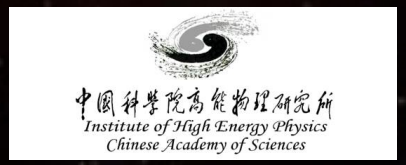
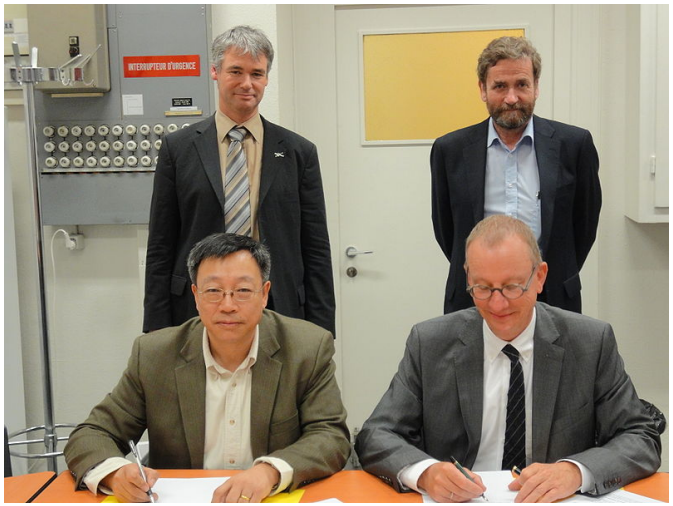
POLAR: the gamma-ray burst polarimeter onboard China's Tiang-Gong 2 Spacelab

Shuang-Nan Zhang
Institute of High Energy Physics, CAS
On behalf of the POLAR collaboration



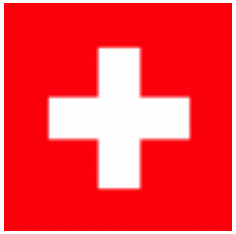
Collaborations of POLAR

PIs:
Shuang-Nan Zhang
Martin Pohl



China

Switzerland



Poland

Institute of High Energy Physics
Chinese Academy of Sciences

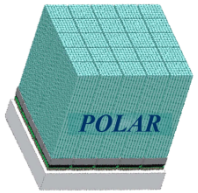
UNIVERSITÉ DE GENÈVE

ISDC

Center for Astroparticle Physics
GENEVA

PAUL SCHERRER INSTITUT
PSI

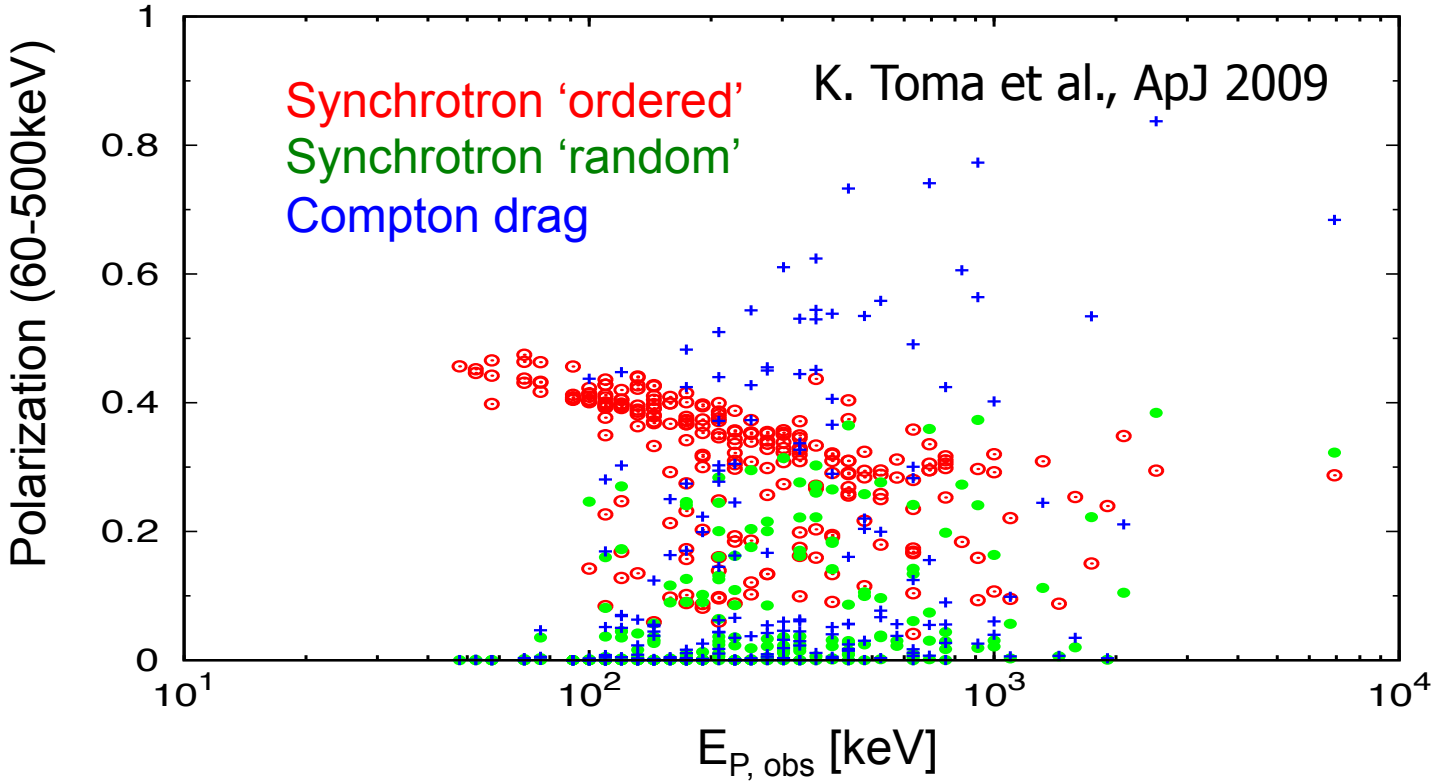
Outline



- Science of POLAR
- Design of POLAR detector
- Performance Study by Monte-Carlo Simulations
- Study of systematic effects
- Calibration tests and data analysis
- In-orbit calibration scheme
- Preliminary results
- Summary and Outlook

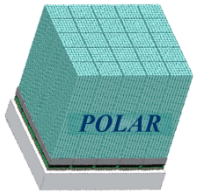
GRB Models and Polarization

The leading models that describe the prompt emission are based on synchrotron emission from relativistic electrons in GRB jets



To discriminate between models: $\Pi \sim$ 10%

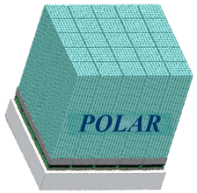
Summary of the current GBR polarization measurements



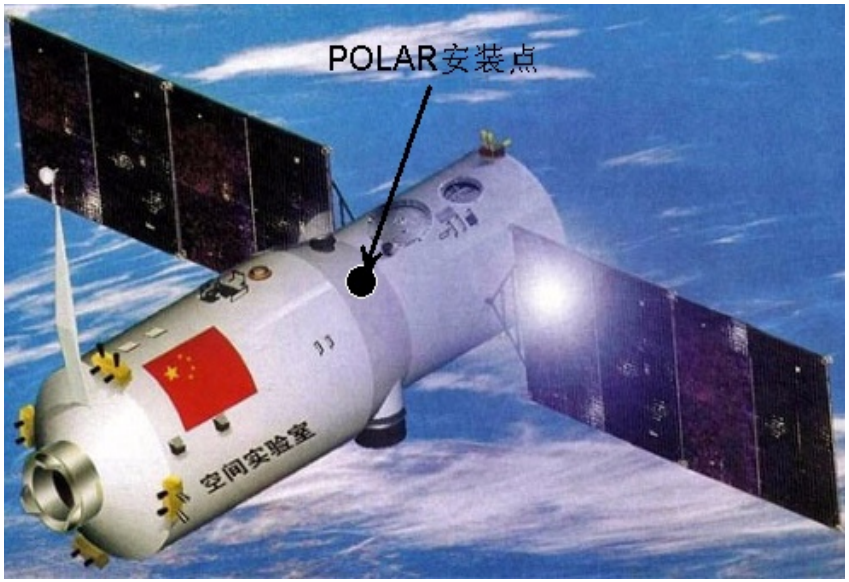
Essentially all with large uncertainties

GRB	Instru/Satellites	Pol degree(%)	Energy range(keV)	Comments
110721A	GAP/IKAROS	84^{+16}_{-28}	70-300	@3.3σ, with constant pol direction
110301A	GAP/IKAROS	70±22	70-300	@3.7σ, with constant pol direction
100826A	GAP/IKAROS	27±11	70-300	@2.9σ, with inconstant pol direction
021206	RHESSI	80±20; 41^{+27}_{-44}	150-2000	With large systematic error
140206A	IBIS/INTEGRAL	>48	200-400	Unable to restrict GRB model
061122	IBIS/INTEGRAL	>60; >65; >52	250-800; 250-350; 350-800	Unable to restrict GRB model
041219A	IBIS/INTEGRAL IBIS/INTEGRAL SPI/INTEGRAL	<4; 43±25; 98±33	200-800; 200-800; 100-350	With variable pol direction
960924	BATSE/CGRO	>50	20-1000	Unable to restrict GRB model
930131	BATSE/CGRO	>35	20-1000	Unable to restrict GRB model

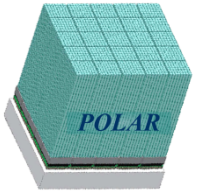
Design of POLAR detector



- **Main scientific goals**
  - Measure the polarization of the GRB prompt emissions as well as Solar flare emissions, to confirm or restrict the radiation models
  - In 2 years of flight lifetime, be able to measure ~ 100 GRBs, contributing to the largest GRB prompt emission polarization observation database
  - For the GRBs with fluence higher than 10^{-5} erg cm^{-2}, the Minimum Detectable Polarization (MDP) of POLAR can reach down to < 10%

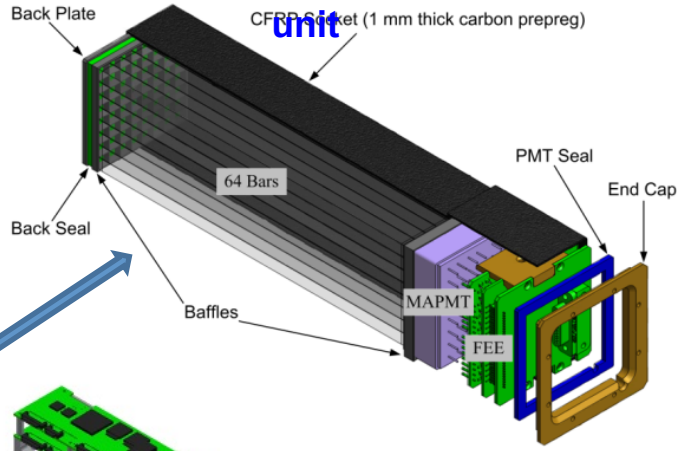


POLAR- composition and construction

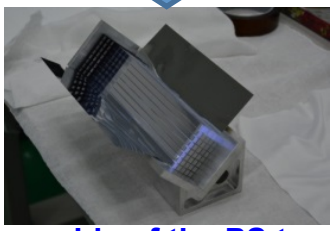


Electric cabinet—IBOX

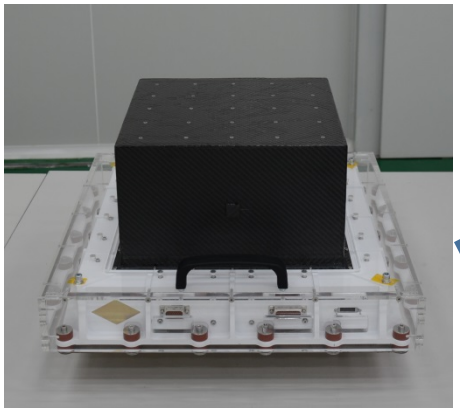
Detector modular unit



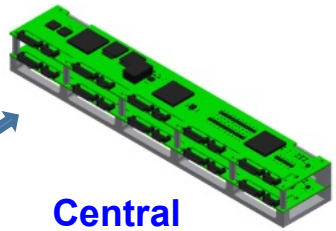
Plastic scintillator bars



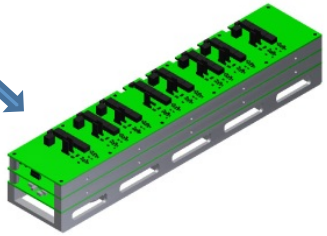
Assembly of the PS target



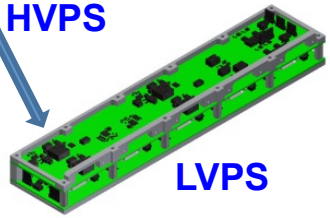
Detector—OBOX



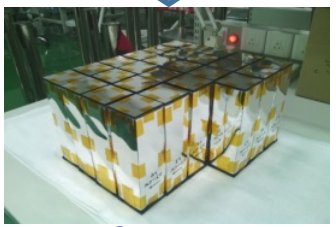
Central



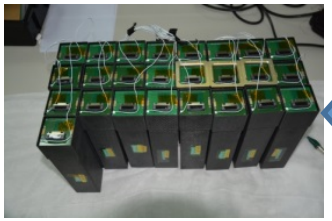
HVPS



LVPS



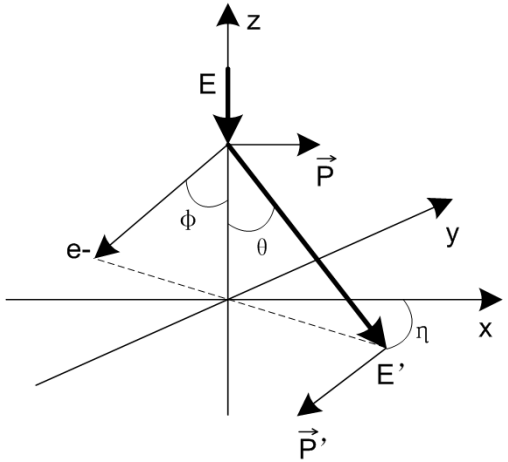
PS targets



Assembled DMUs

Naked DMU

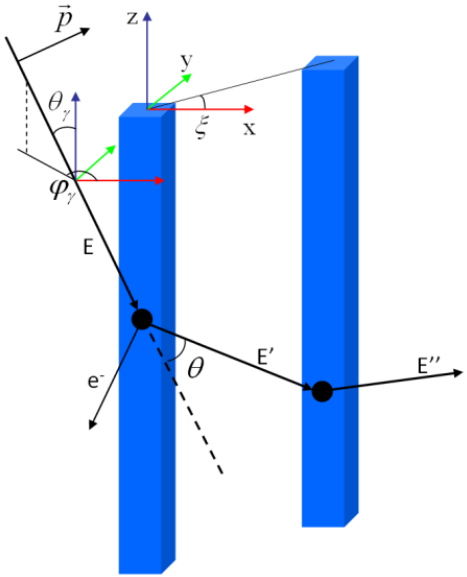
Detection principle of POLAR



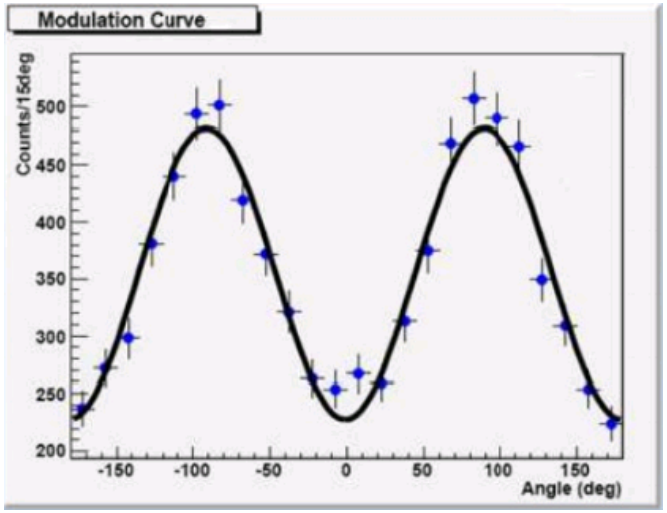
Compton Scattering with larization

Klein-Nishina equation:

$$\frac{d\sigma_P}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 (\varepsilon + \varepsilon^{-1} - 2\sin^2\theta\cos^2\eta)$$



Detection principle of POLAR



Modulation curve

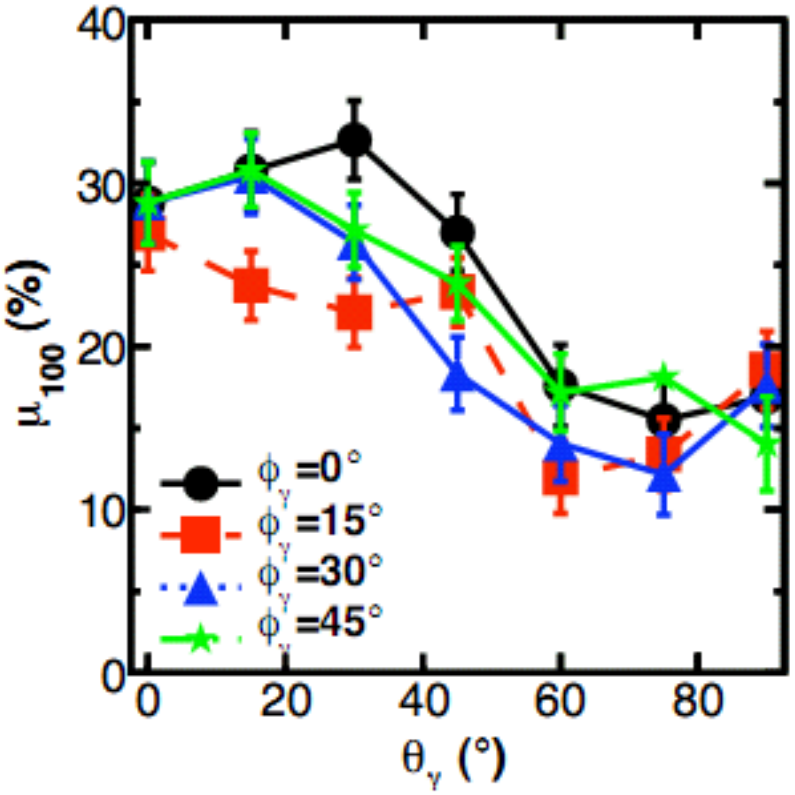
Distribution function

$$C(\xi) = A\cos(2(\xi - \varphi + \frac{\pi}{2})) + B$$

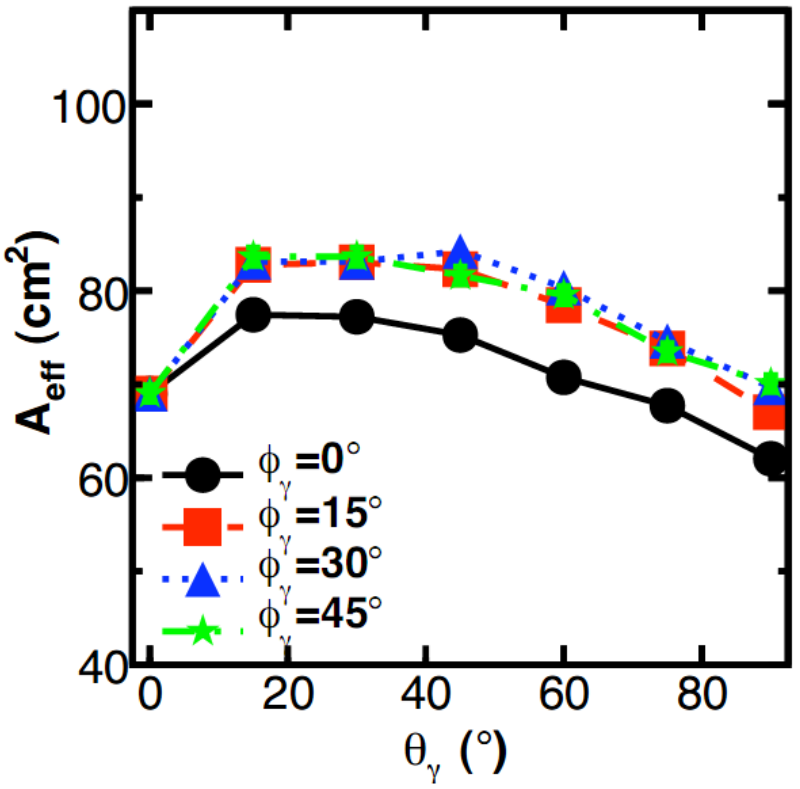
$$\mu = \frac{C_{max} - C_{min}}{C_{max} + C_{min}} \Rightarrow P = \frac{\mu}{\mu_{100}}$$

Modulation factor Polarization level

Monte-Carlo Simulations - Modulation Factor & effective area

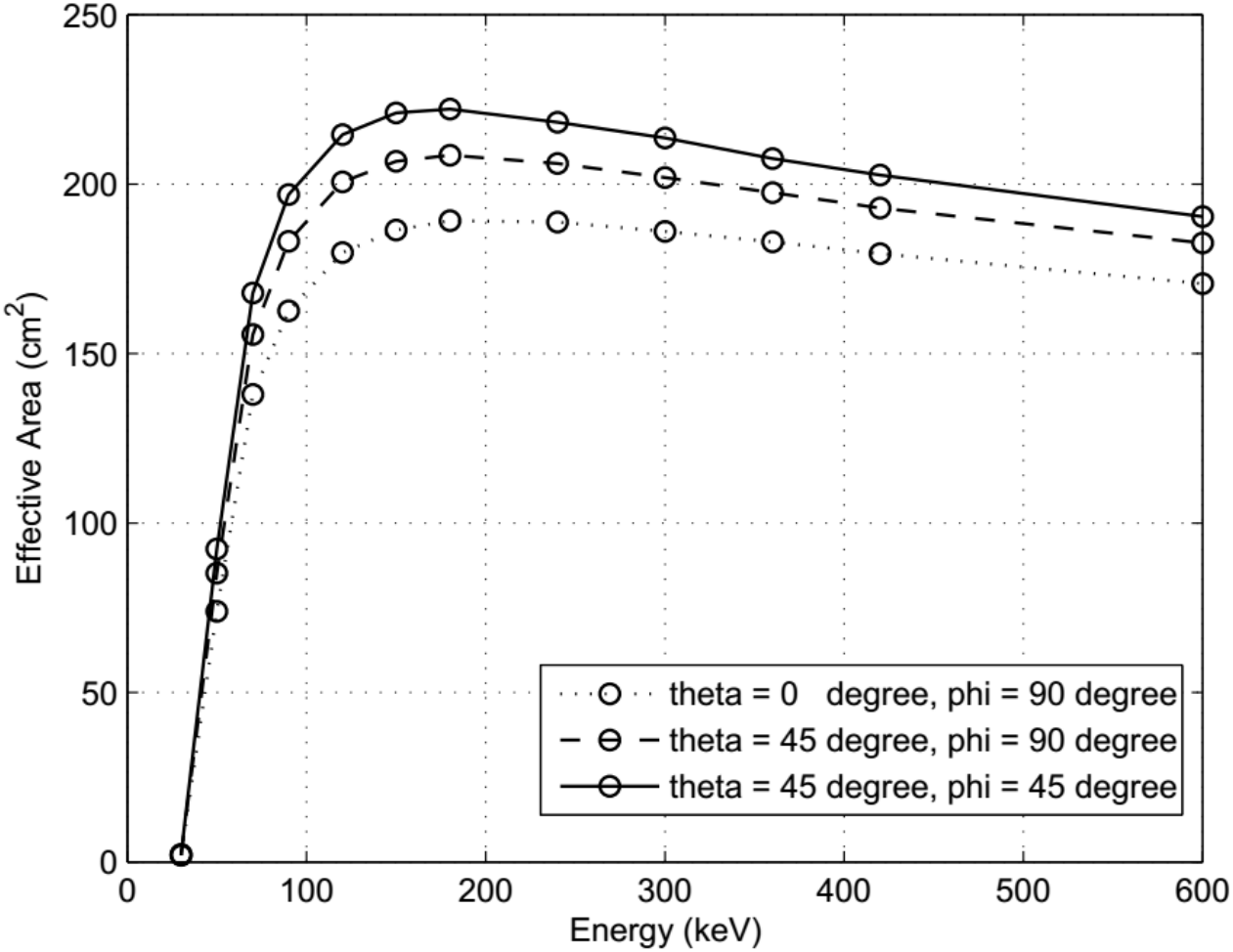


Modulation factor varies with incident direction of the photons. E. S. Garcia, 2010



Effective area of POLAR calculated for a standard GRB. E. S. Garcia, 2010

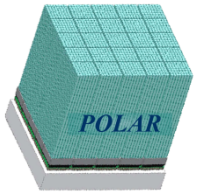
Monte-Carlo Simulations - Effective area



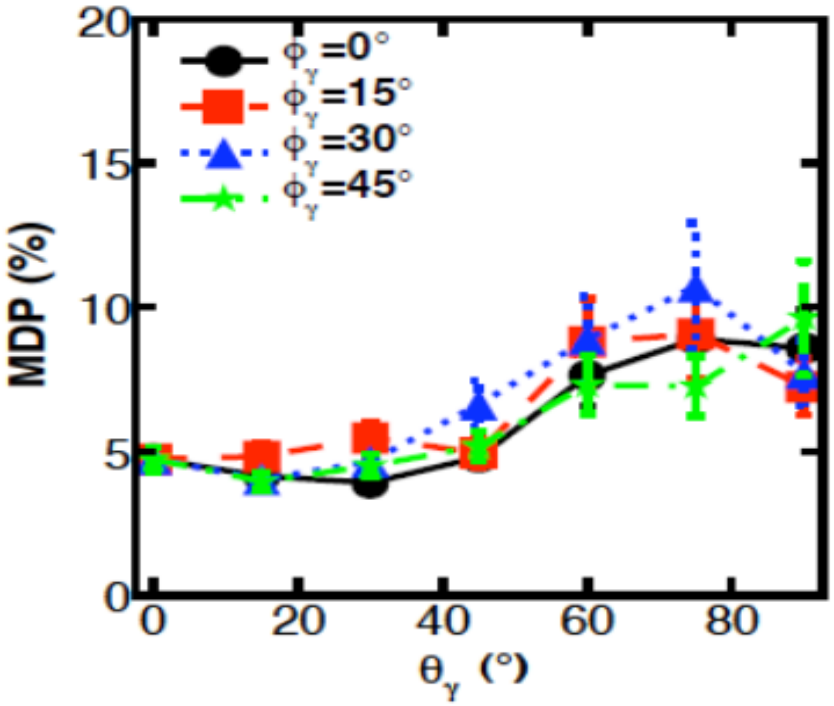
Effective area vs Energy

Shaolin Xiong Ph.D. thesis, 2010

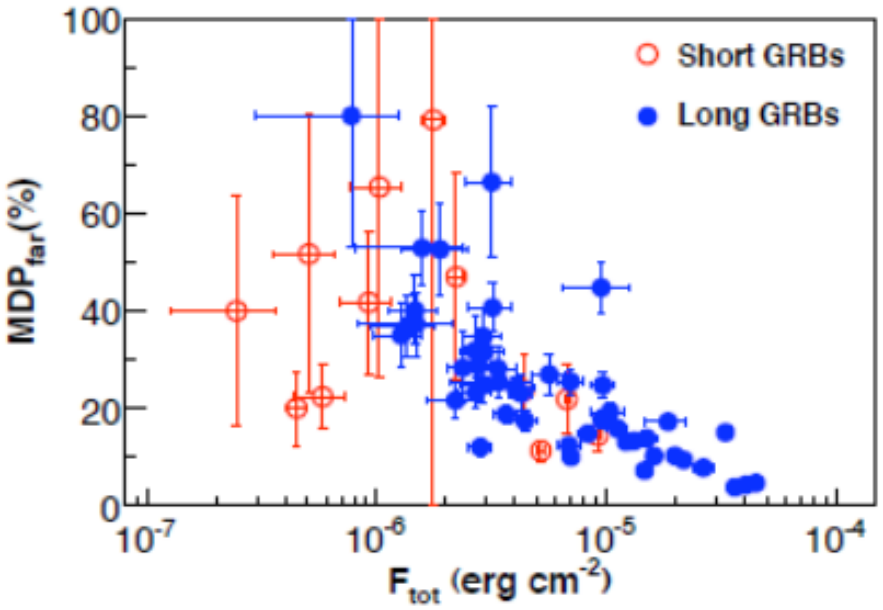
Monte-Carlo Simulations – Minimum detectable polarization



$$MDP = \frac{n_\sigma}{S_F \mu_{100} \varepsilon A} \sqrt{\frac{S_F \varepsilon A + B}{T}}$$

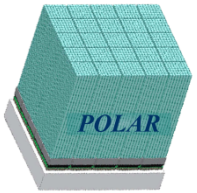


MDP varies with incident direction of the GRB photons. E. S. Garcia, 2010



MDP varies with total fluence given in the BATSE catalog for photons with energy above 20 keV. E. S. Garcia, 2010

Technical properties summary of POLAR

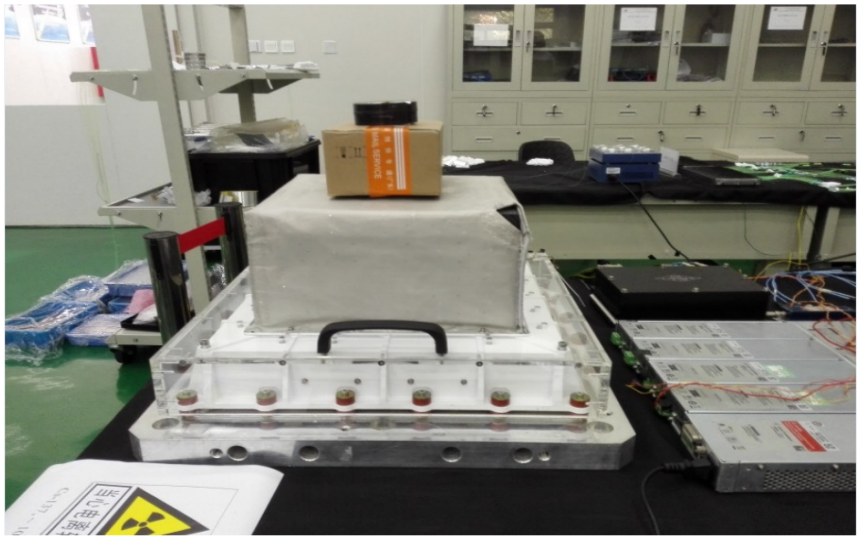


1	Detector material	Plastic scintillator (EJ-248M)
2	Yearly detectable GRBs	~50
3	GRB localization accuracy	≤5°(Fluence≥10^{-5} erg cm^{-2})
4	Detection energy range	～50－500 keV
5	Field of view	±70°×±70°（~1/3 of the sky）
6	Modulation factor	40%@200 keV
8	MDP	～10%　（$Fluence_{total}$ ≥ 3×10^{-5} erg cm^{-2}）
9	Detector geometry area	~550 cm^2 (on-axis view)
10	Mass	OBOX: 27.6 kg, IBOX: 3.52 kg
11	Size	OBOX: 462×462×268.5 mm^3 IBOX: 247×160×85 mm^3
12	Maximum power consumption	≤80 W
13	Time accuracy(UTC)	±1 ms
14	Reliability	0.90（in 2 years lifetime）

Calibration tests and data analysis

(1) Calibration tests with radioactive source

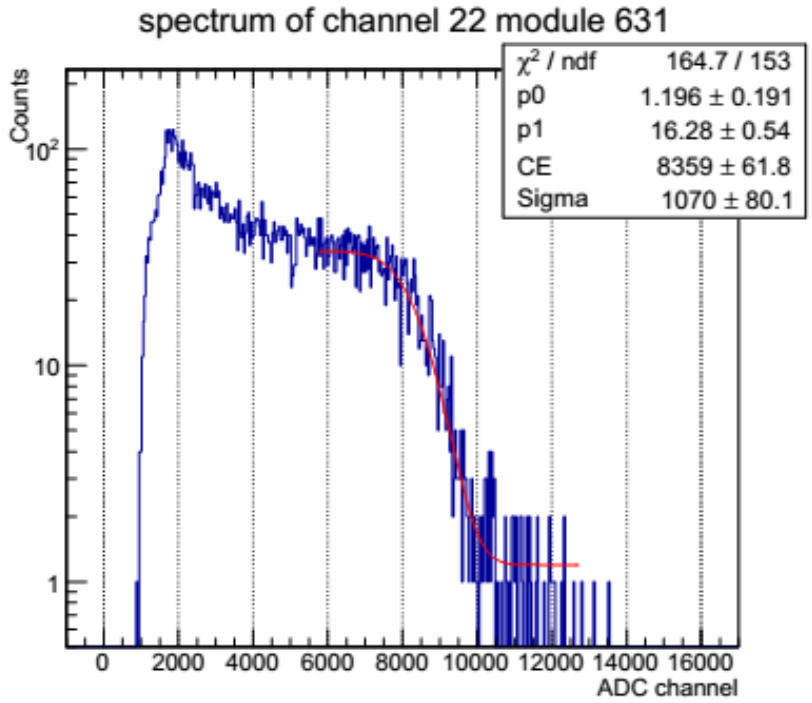
- **Instruments:** OBOX FM, IBOX FMS, EGSE
- **Aim:** Gain-HV calibration, energy calibration
- **Source:** ^{137}Cs (662 keV Gamma-rays, ~477 keV of the Compton edge)

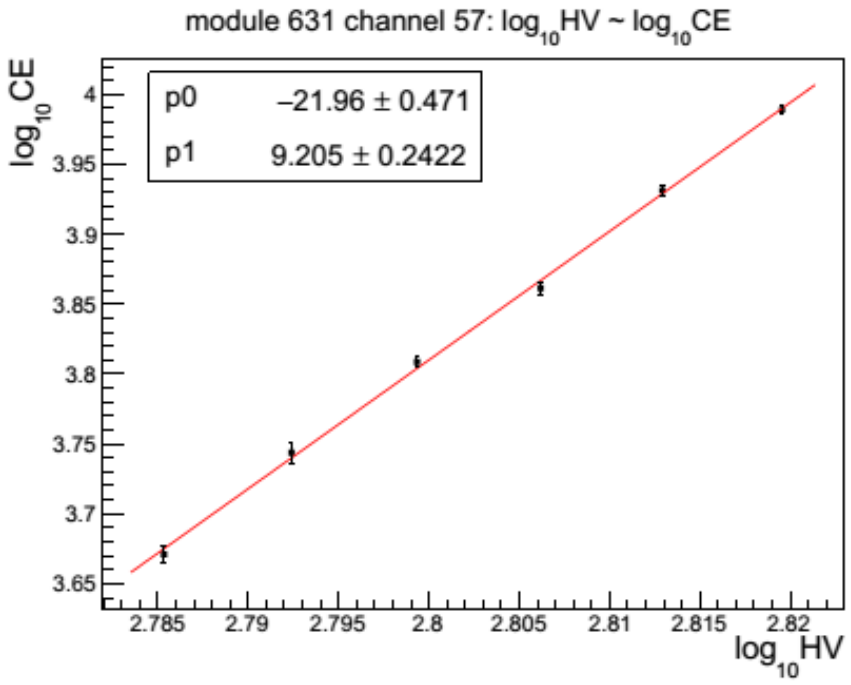


Tests at IHEP

Calibration tests and data analysis

(1) Calibration tests with radioactive source



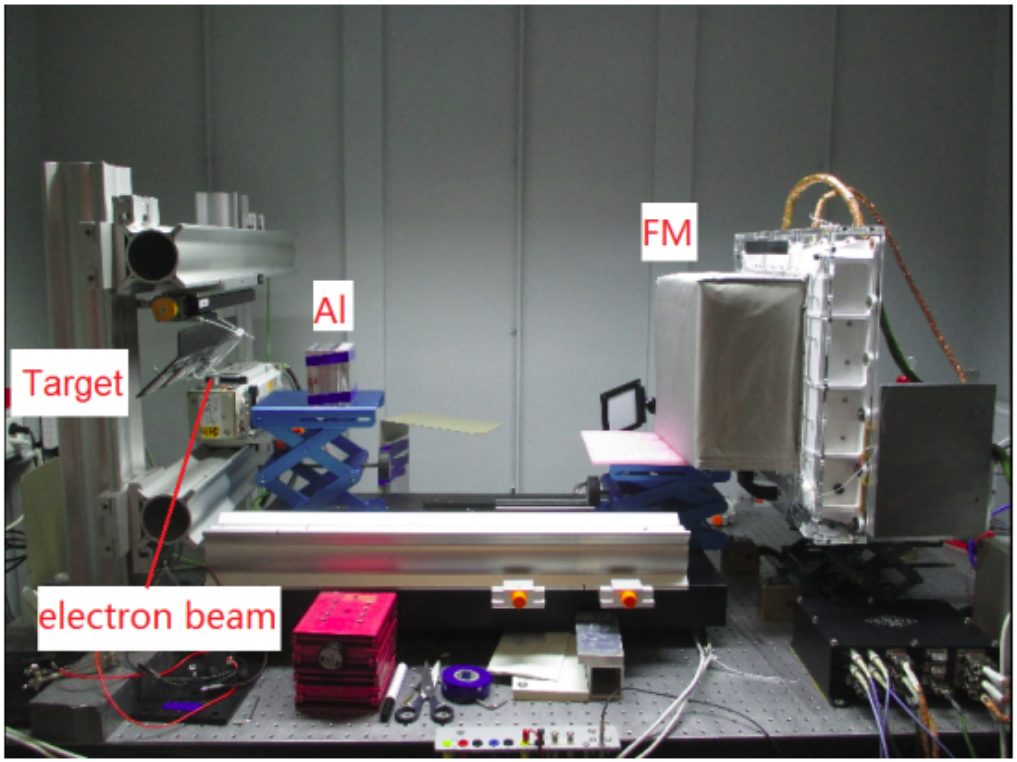


Left: Compton spectra and fitting curve of channel 22 of module 631; Right: $\log_{10}$CE vs $\log_{10}$HV of channel 57 of module 631

Calibration tests and data analysis

(2) Calibration tests with low energy X-ray fluorescence

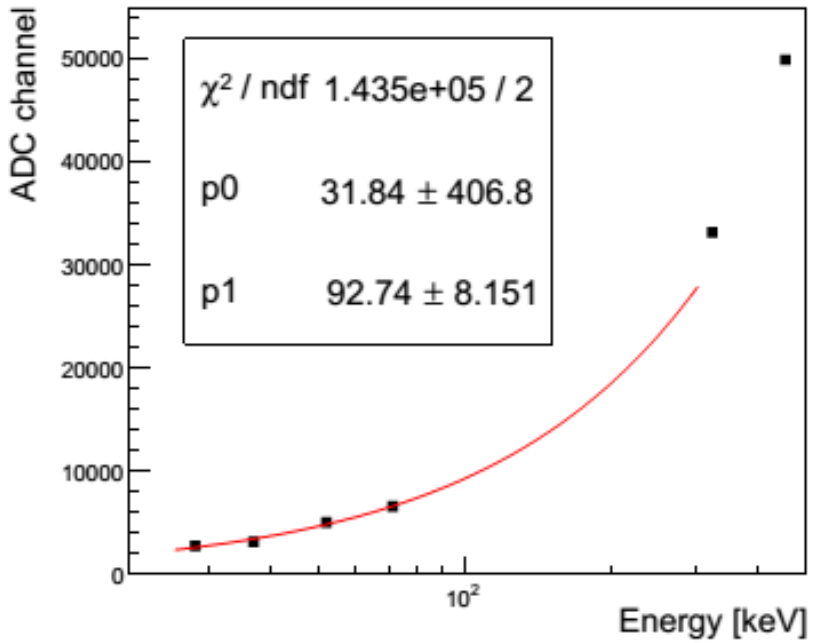
- **Instruments:** OBOX FM, IBOX FMS, EGSE
- **Aim:** Low energy calibration, E-C relation calibration
- **Source:** X-ray fluorescence (34.5keV, 44keV, 60keV, 80keV)

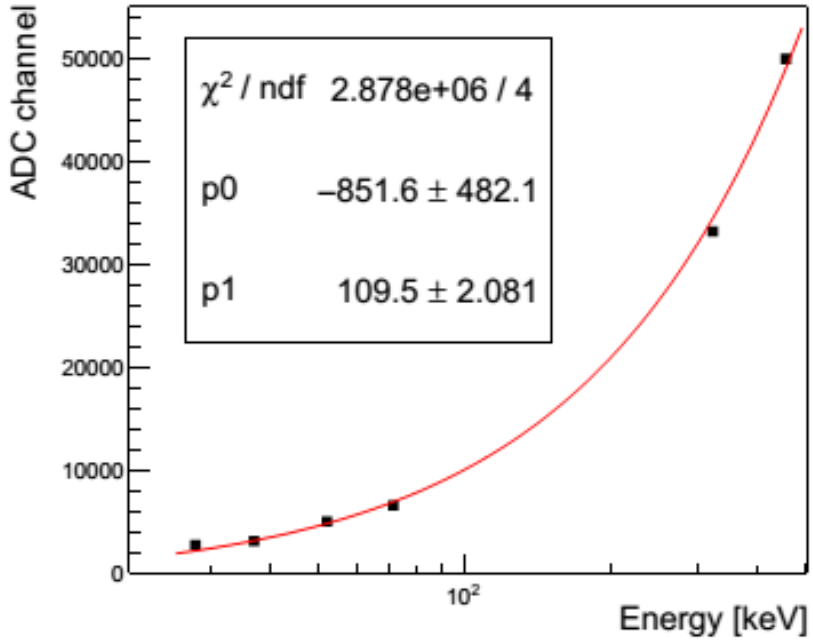


Tests at IHEP

Calibration tests and data analysis

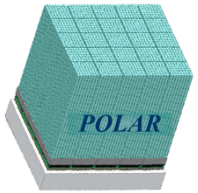
(2) Calibration tests with low energy X-ray fluorescence





Calibrated E-C relations of channel 31 of module 423, HV = -810V. Black points: data; Red curve: fitting curve. Left: fitting with only the first 4 data points; Right: fitting with the first 4 measured data points + 2 calculated data points according to the Gain-HV relations。

Calibration tests and data analysis



(2) Calibration tests with low energy X-ray fluorescence

E-C relation energy, FEE temperature and HV

Incident energy/keV	34.5	44	60	80	511	662
Energy deposition/keV	28.1	37.0	52.2	71.4	322.8	456.0
FEE average temperature/℃	41.3	37.6	43.2	44	-	31.4
HV/V	init56	init56	init56	init56	init57	610 ~ 660

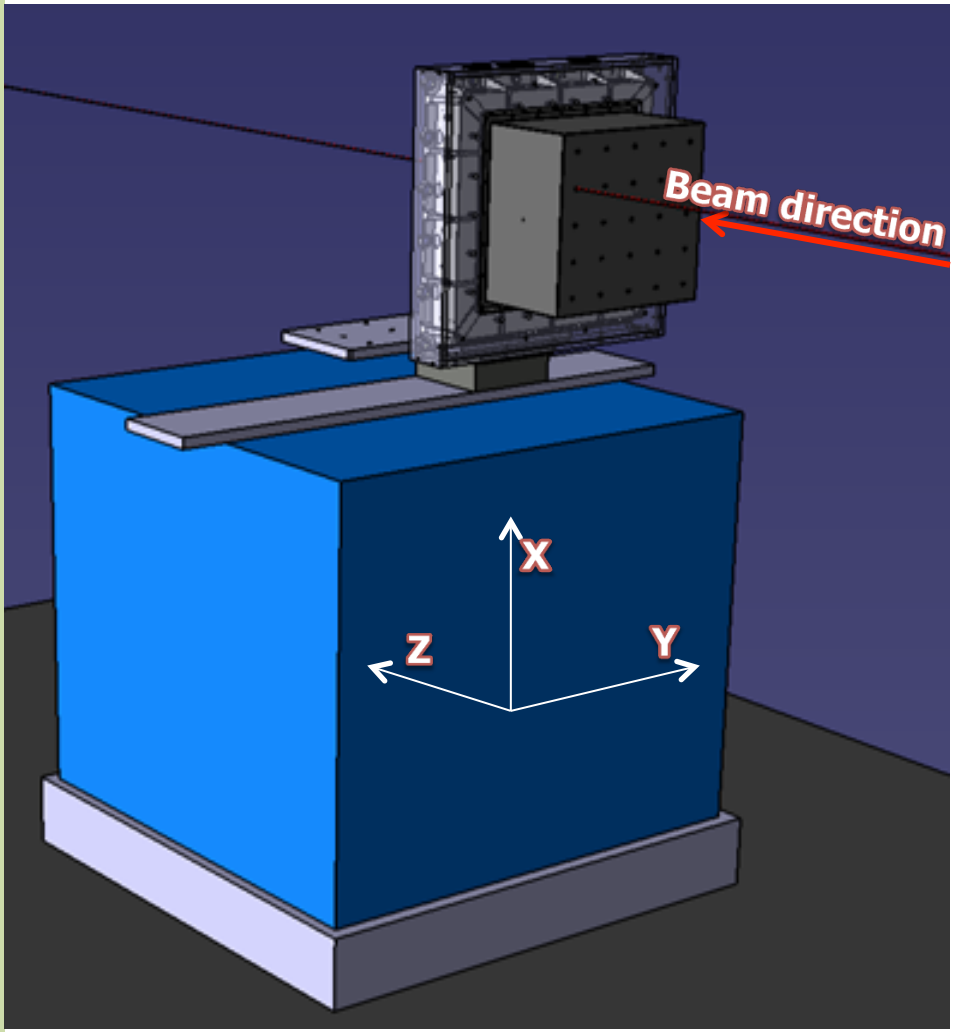
* The Compton edge position are used for 511 keV and 662 keV. kB = 0.143 mm/MeV

* Init56 and init57 are different detector parameter settings (here the main difference is the HV) for the tests

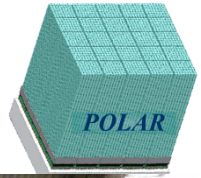
Calibration tests and data analysis

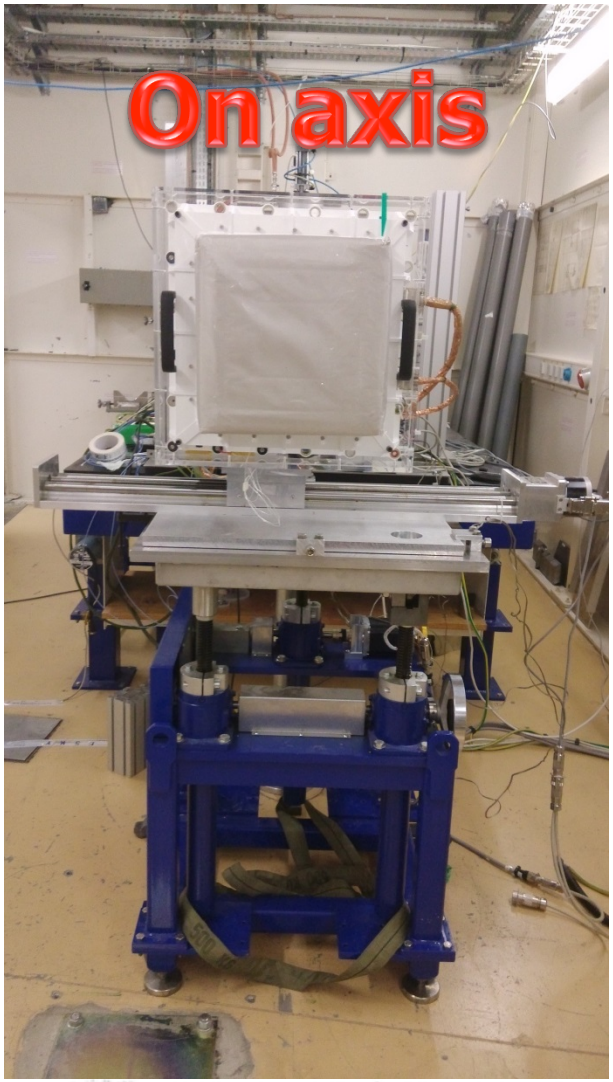
(3) ESRF beam test in 2015 - introduction

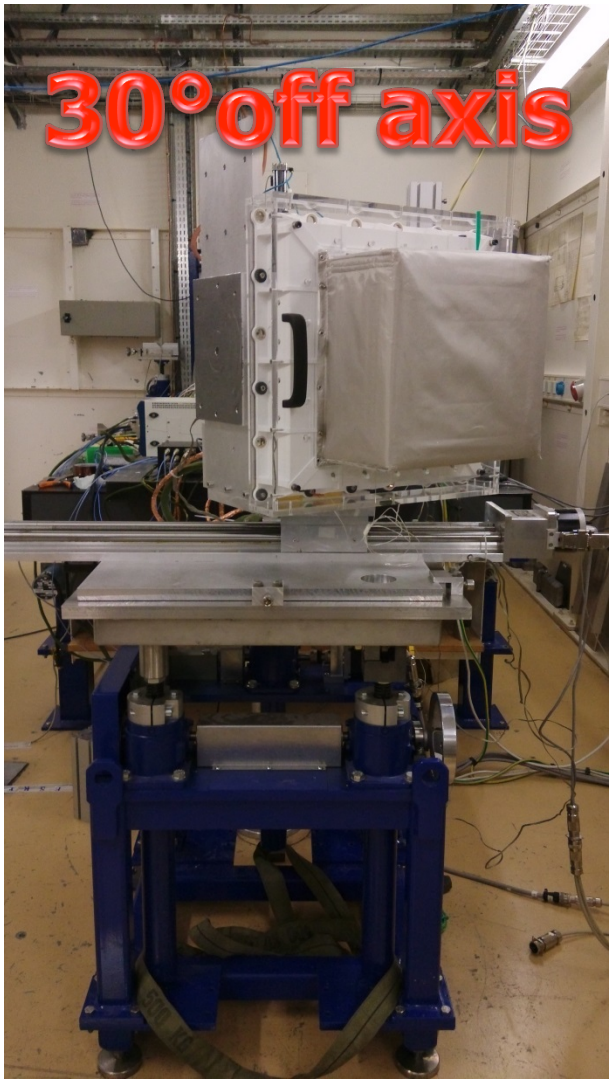
- **Facility introduction**
  - Beamline: ID11
  - Polarization: 100%
  - Pol direction: horizontal
  - Energy range: 35 ~ 140 keV
  - Beam size: minimum (H×V) 0.2×0.07 μm^2, maximum (H×V) 1200×1000 μm^2
  - Initial intensity：~10^7 phs/s

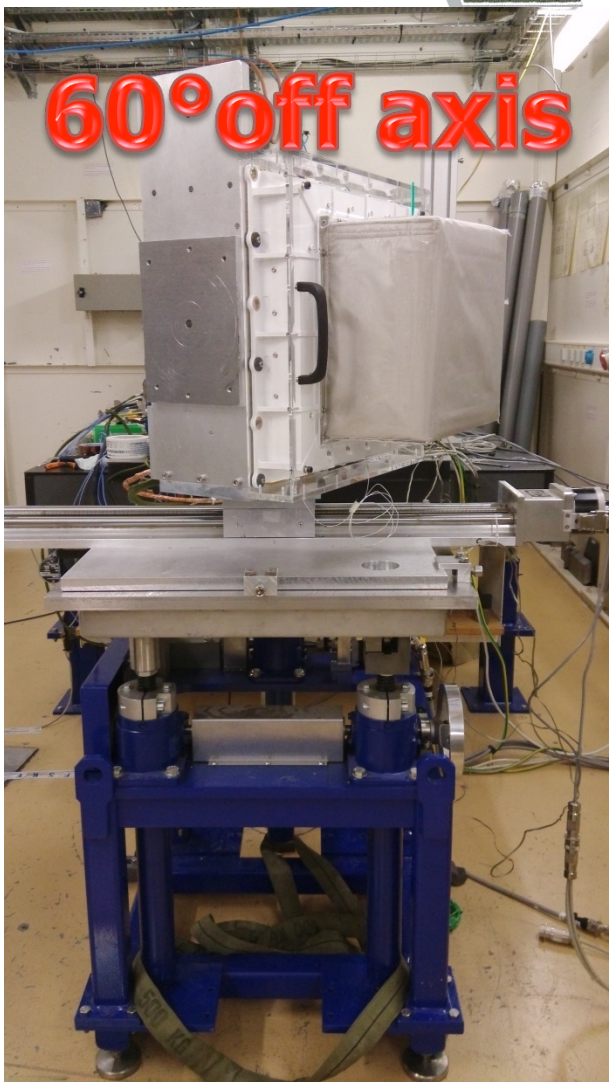


Detector positions for different off-axis tests

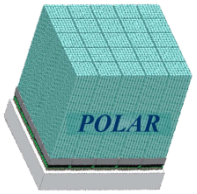








Data reduction procedure

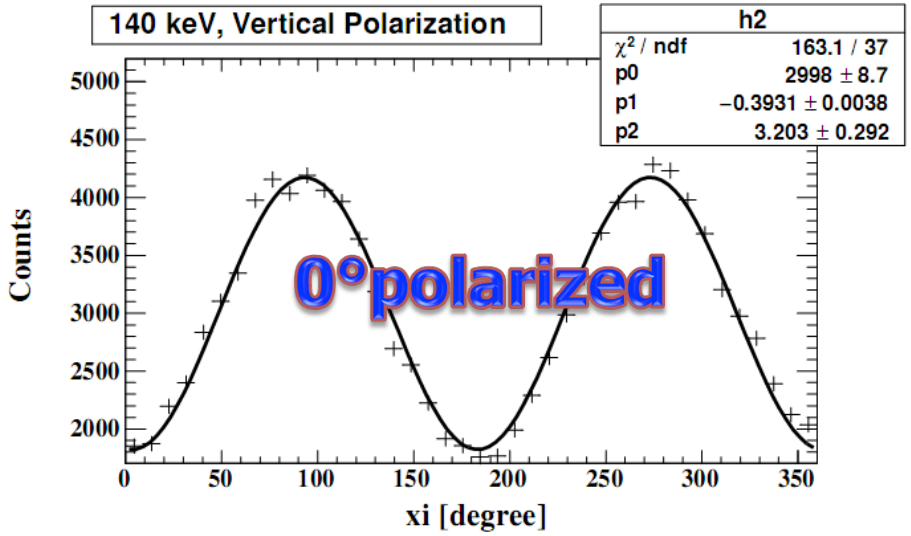


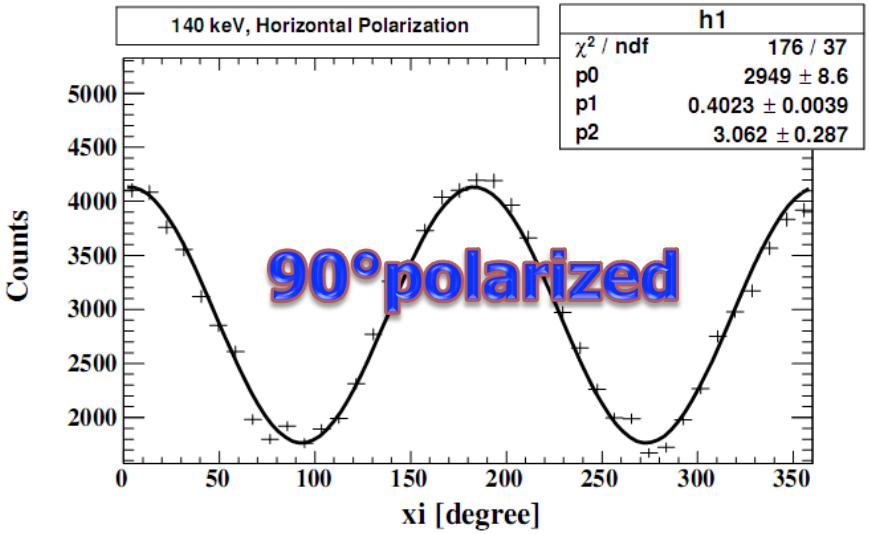
- **General data analysis procedure**
  - *Cleaning and selecting of the data*
  - *Integration of the data files*
  - *Pedestal and common noise subtraction*
  - *Calculation of "barbeam" information*
  - *Crosstalk correction*
  - *Event time synchronization and merge*
  - *Energy calibration*
  - *Modulation curve filling*
  - *Geometric effect correction*
  - *Modulation factor calculation*
  - *Comparison with MC simulation results*
  - *…*

Calibration tests and data analysis

(3) ESRF beam test in 2015 - modulation curve calculation results

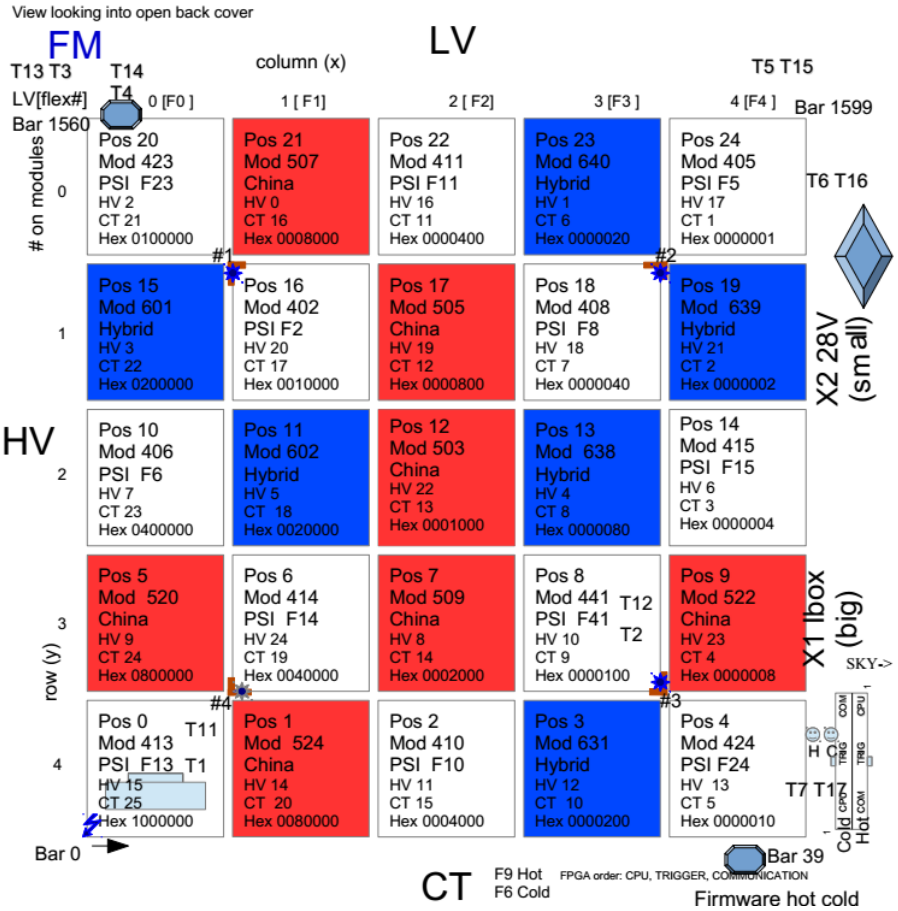
Modulation curve, 140 keV

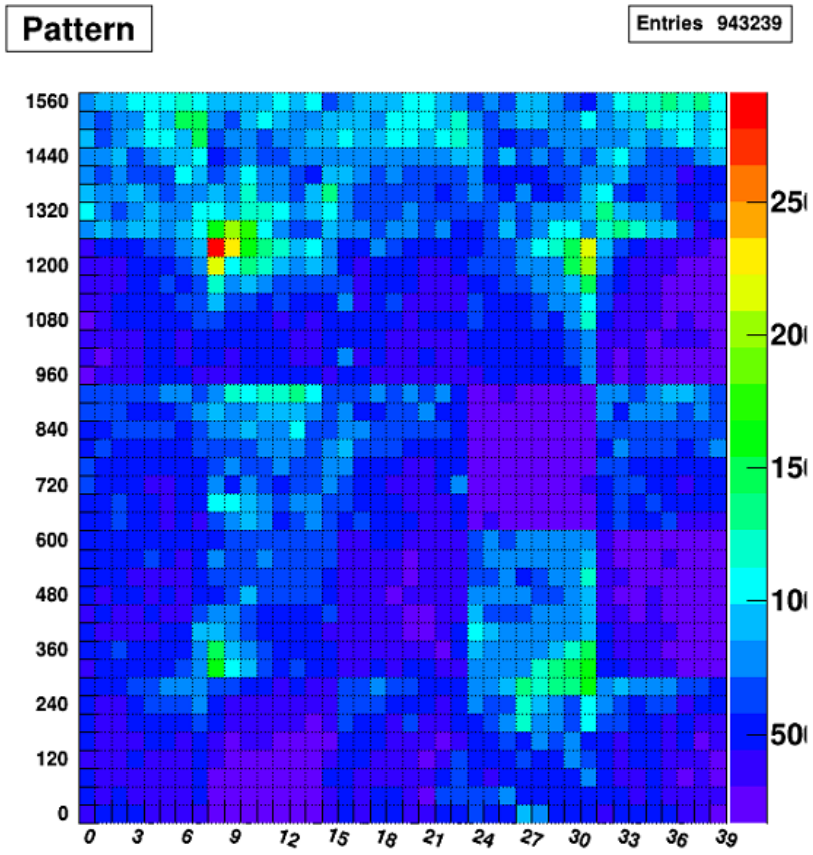




- 140 keV, on-axis measurement
- Modulation factor
  - 0°polarization：39.31%
  - 90°polarization：40.23%
  - Simulated result: ~40%

In-orbit calibration scheme

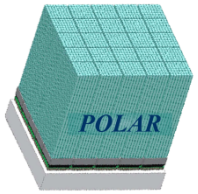




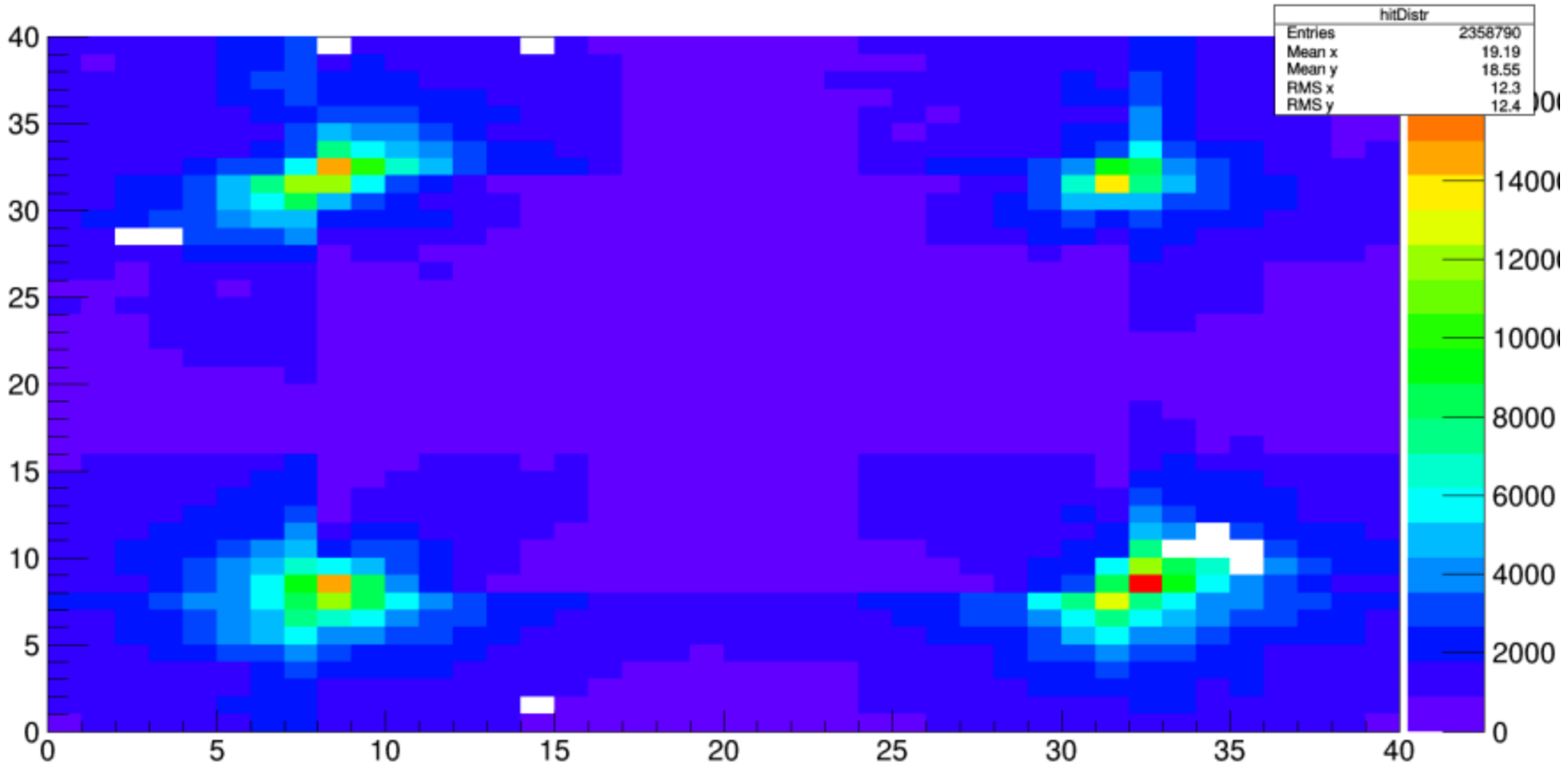
Top view of POLAR: locations of 4 ^{22}Na sources and 25 modules

Triggering pattern of the 1600 channels

In-orbit calibration scheme

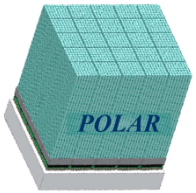


Result with event selection criteria

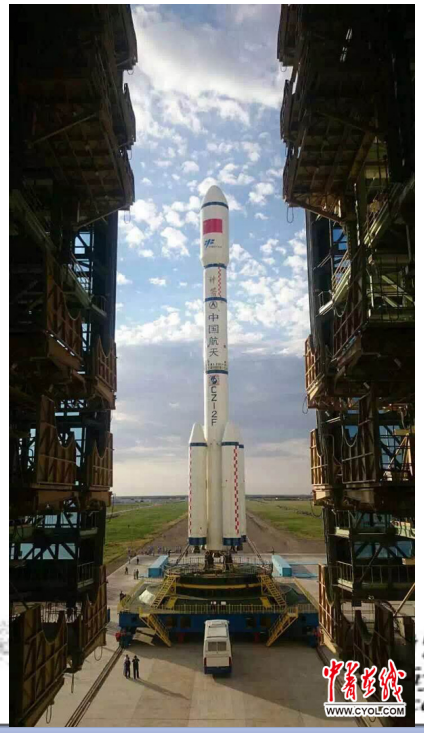


Triggering pattern of the 1600 channels

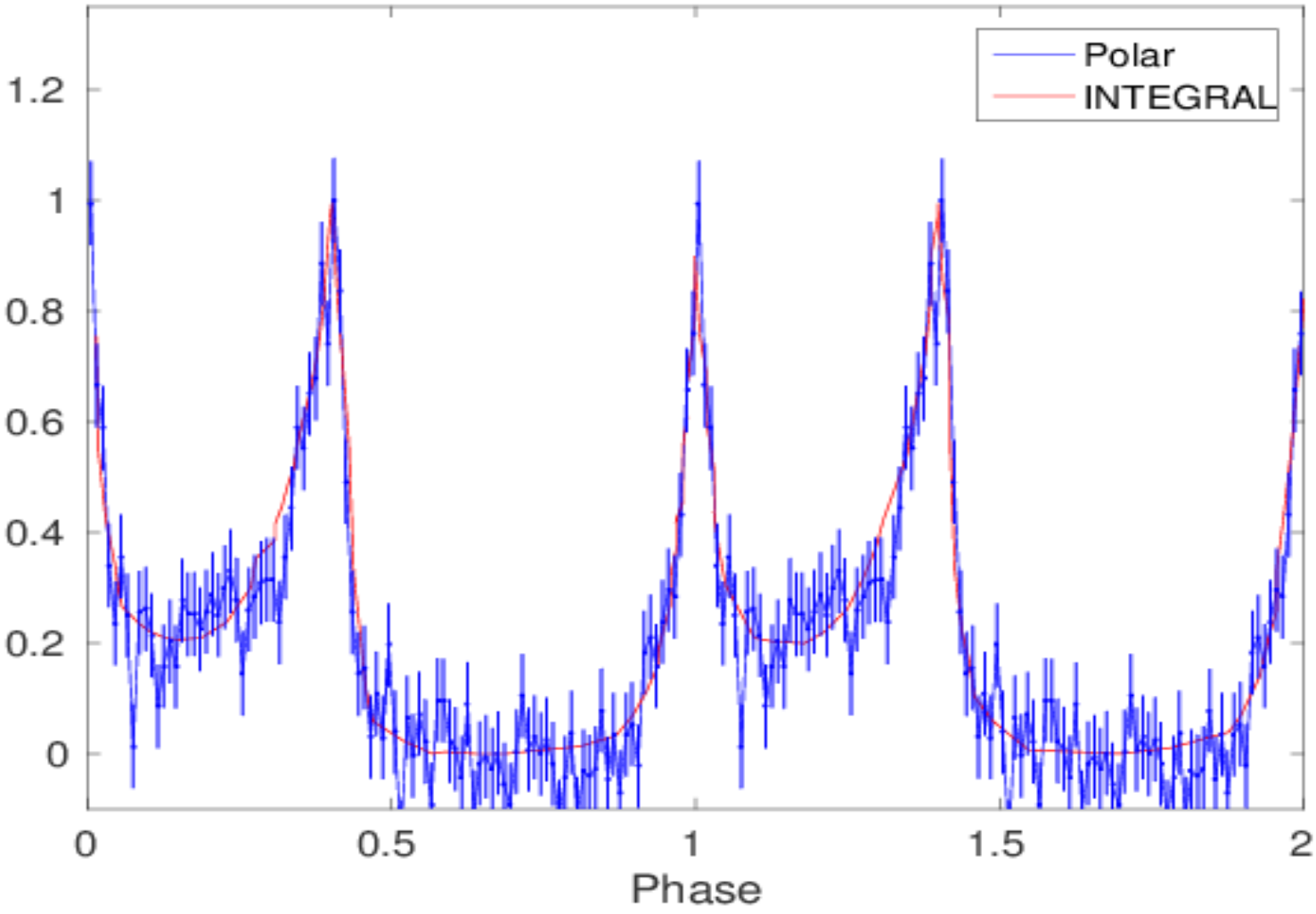
Current status



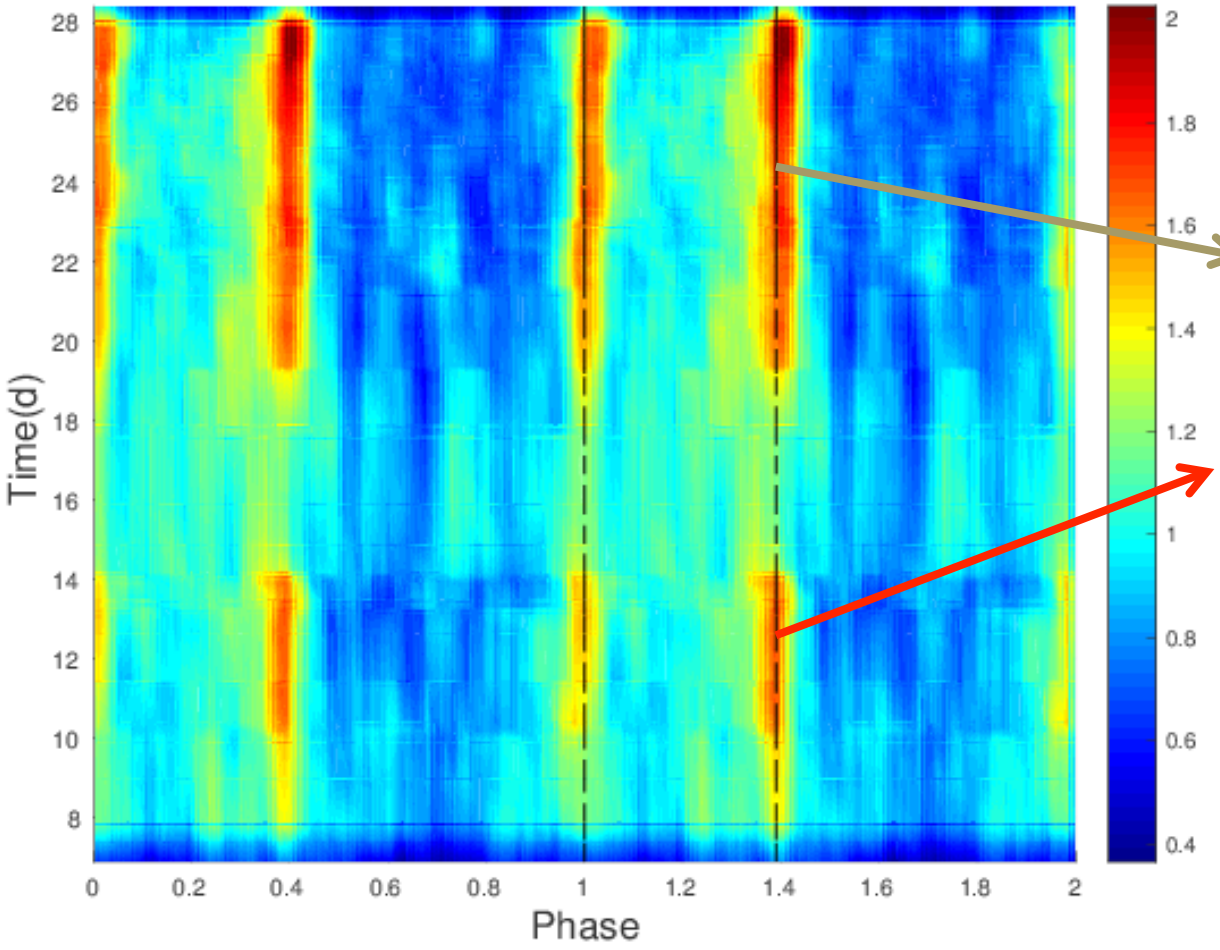
- POLAR was successfully launched on on15th/September
- POLAR was successfully powered on on 16th/September
- OBOX was successfully powered on on 22nd/September
- OBOX was powered off on 14th/October for docking of TG-2 and Shenzhou-11 spaceship
- OBOX was powered on again on 18th/November…



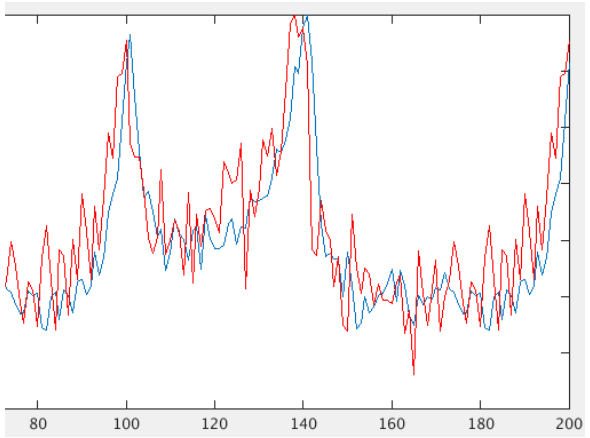
Preliminary results: Crab pulsar



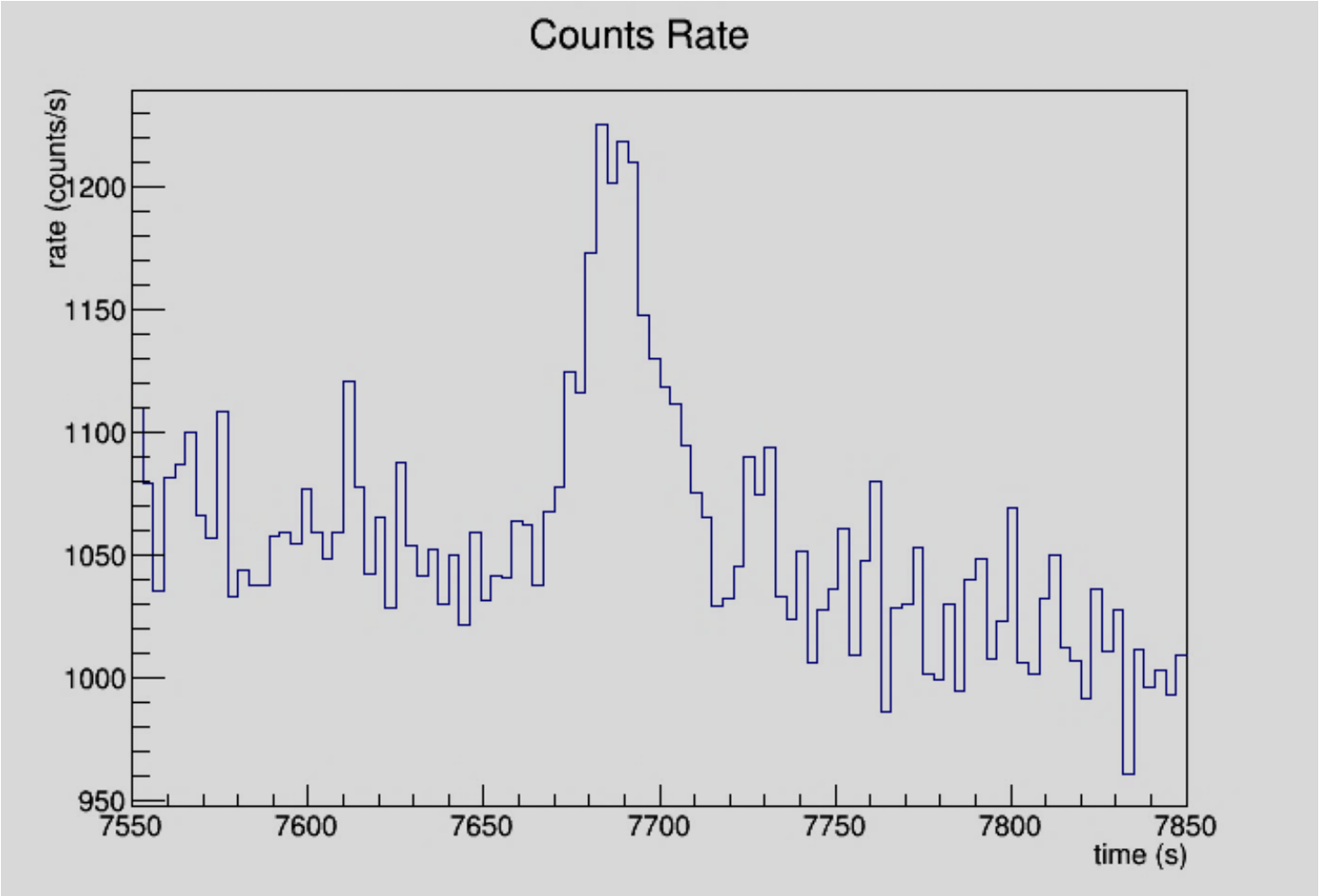
Preliminary results: Crab pulsar



Profile comparison for two days: slight phase difference?

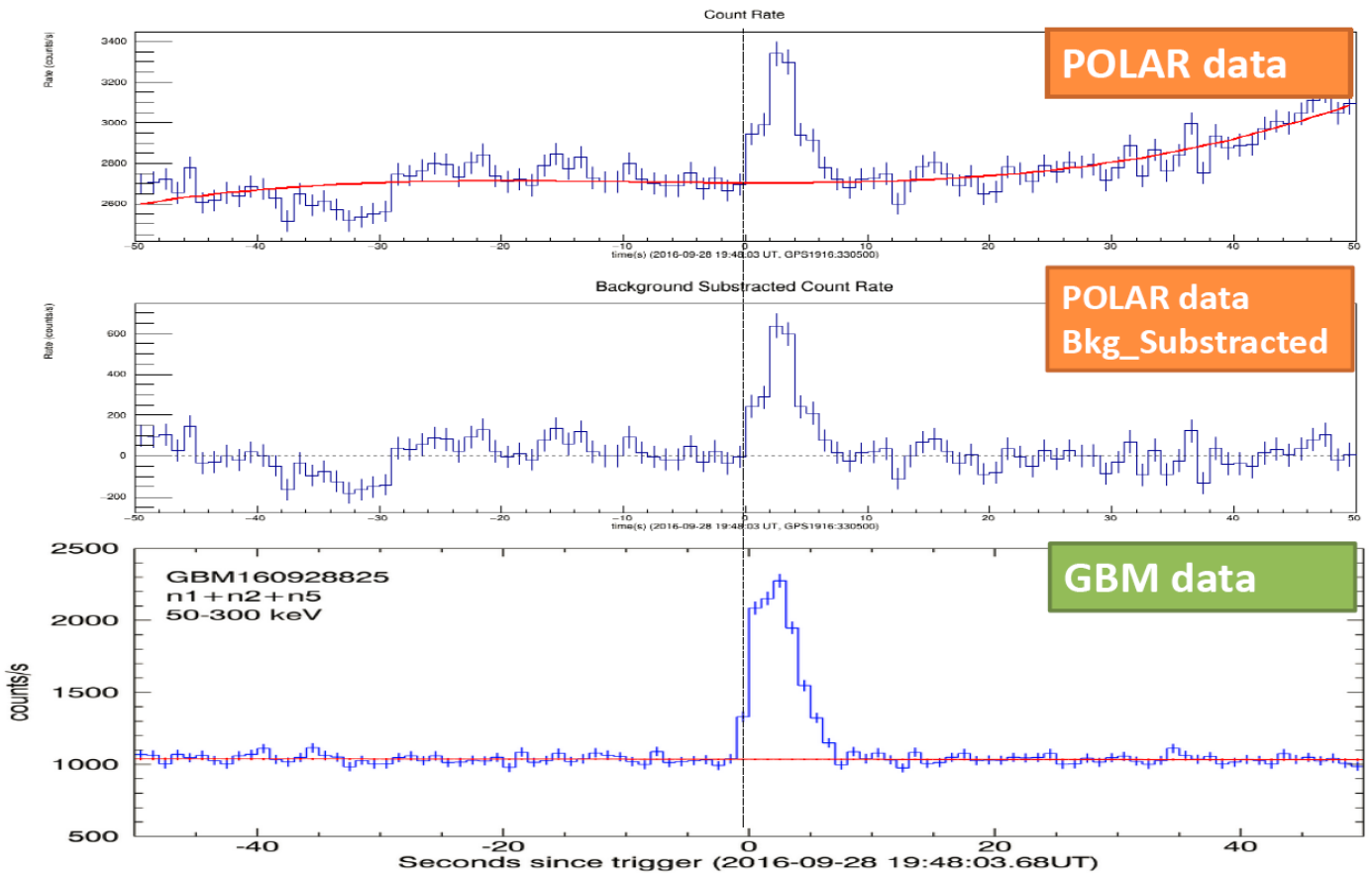


Preliminary results: solar flare



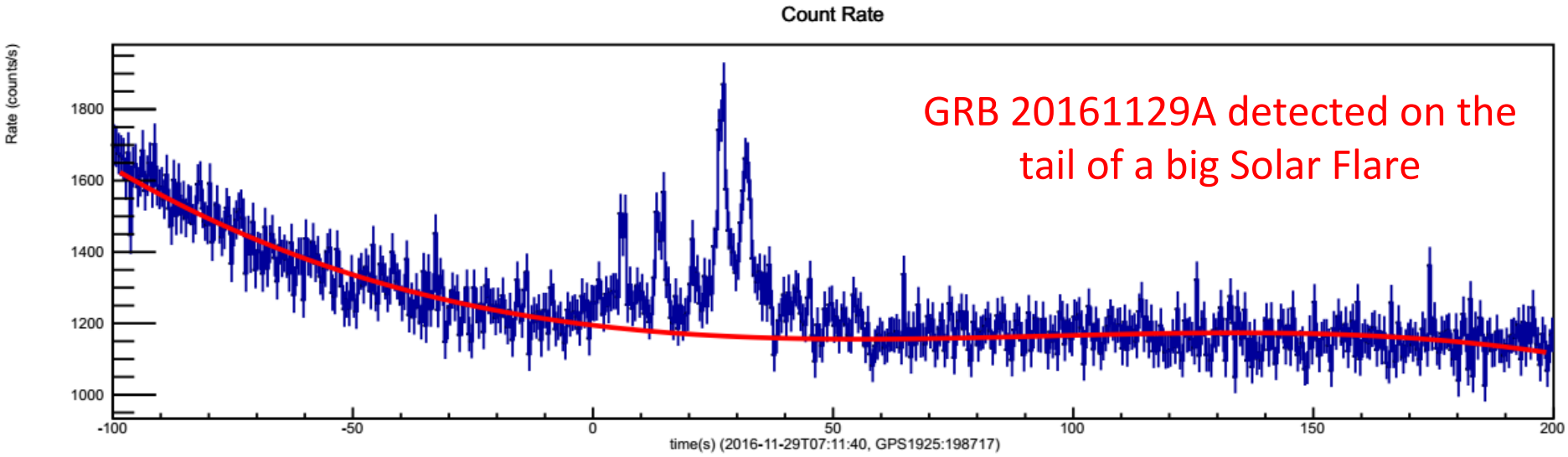
Oct. 12, 2016: consistent with RHESSI results

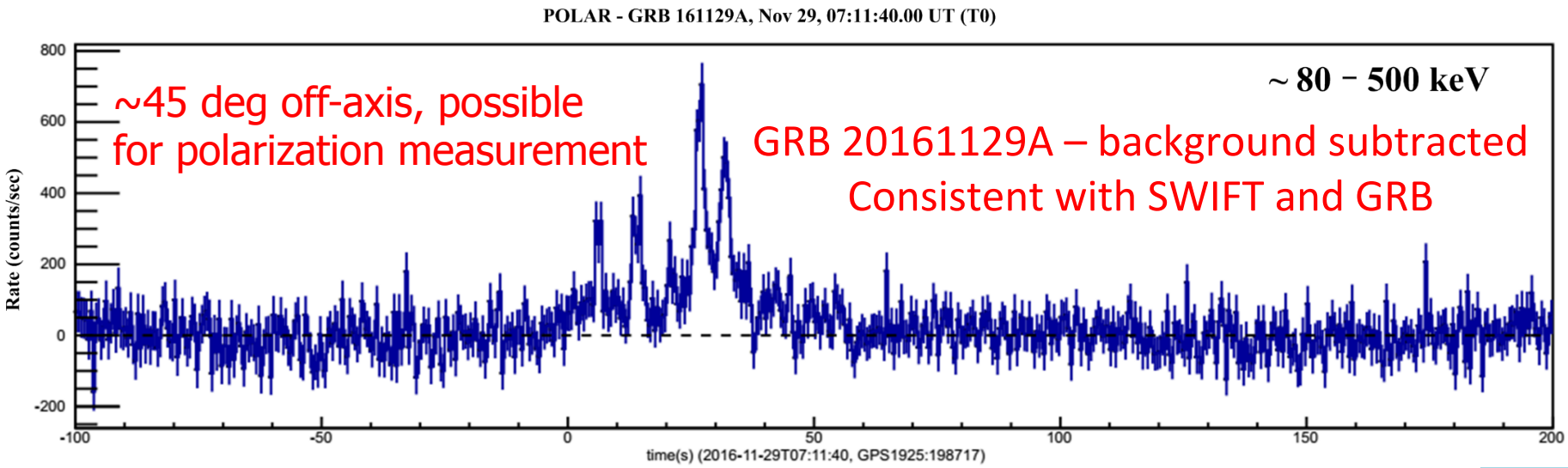
Preliminary results: GRB 20160928A



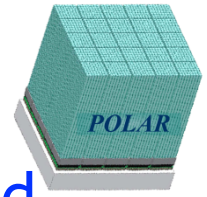
>90 degree off-axis, not good for polarization

Preliminary results: GRB 20161129A





Summary and outlook



- POLAR, launched on 2016-09-14, is working as expected.
- POLAR has detected the Crab pulsar, solar flares and GRBs.
- In-orbit calibration is on-going: polarization for solar flares and GRBs are expected for bright events.
- POLAR data are delayed by about one day, so we can not give fast GRB alerts.
- However, upon receiving GCN notices of GRB alerts, POLAR team can report rapidly the prospect of measuring polarization of each GRB with an estimated uncertainty.

For more details, please refer to the following website or contact us.

http://polar.ihep.ac.cn E-mail: zhangsn@ihep.ac.cn or Martin.Pohl@cern.ch

Thanks for your attention !

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